Multidisciplinary Optimization Methods for Preliminary Design

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Outline

- Definitions
- Requirements for using MDO in Preliminary Design
- Preliminary Design MDO Examples
- Summary

MDO Definition

Multidisciplinary Design Optimization (MDO) is a methodology for the design of complex engineering systems and subsystems ***<u>that coherently exploits the synergism of mutually interacting phenomena</u>***

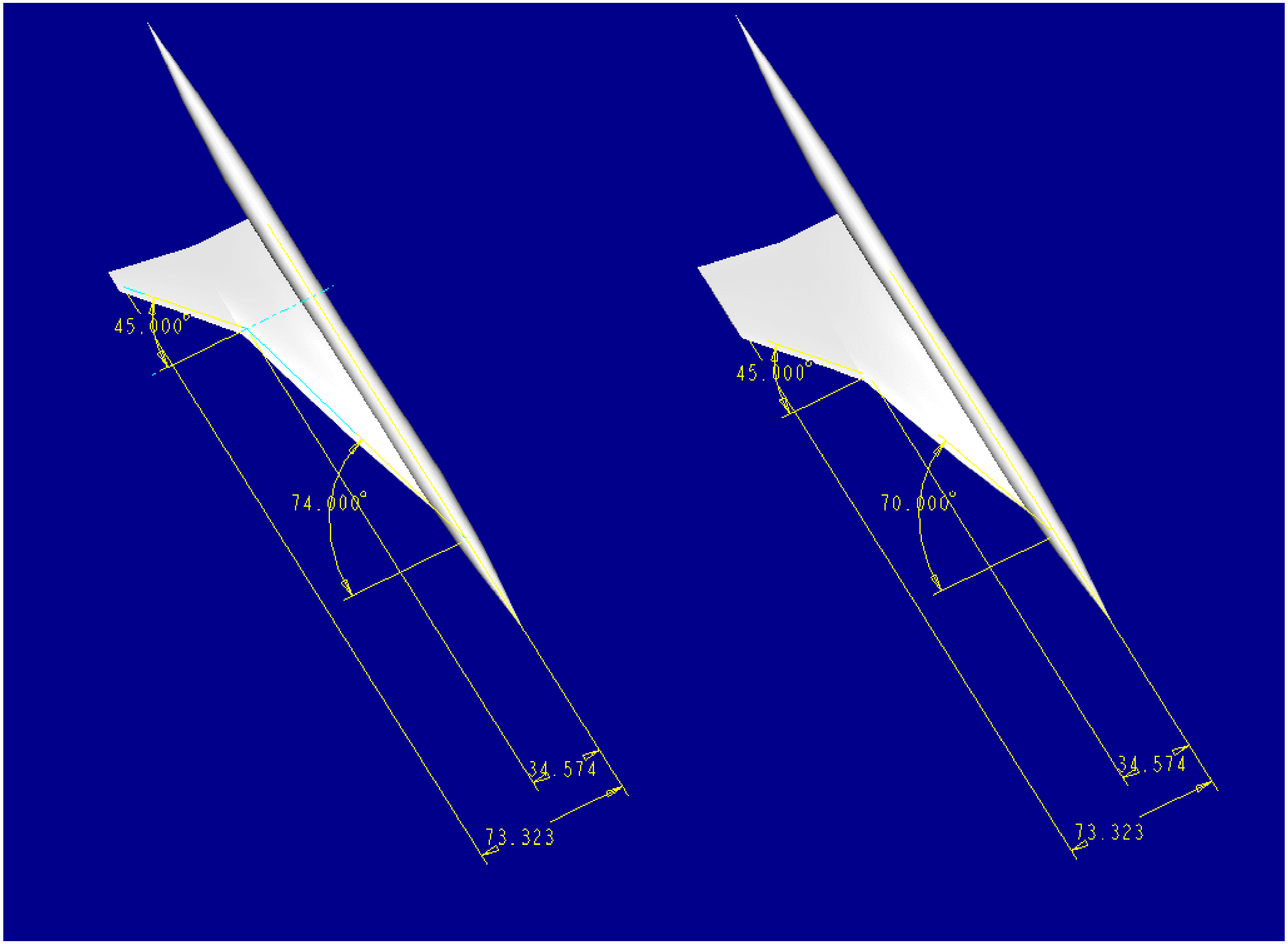
$$\Delta_{\mathbf{Design}} = \left(\sum_{\mathbf{i}} \Delta_{\mathbf{Discipline\ i}}\right) + \Delta_{\mathbf{MDO}}$$

$$\text{“}\Delta_{\mathbf{MDO}}\text{”}$$

MDO Conceptual Elements

Information Science & Technology	Design-Oriented MD Analysis	MD Optimization
Product Data Models	**Mathematical Modeling**	***Discipline Optimization***
Data & S/W Standards	**Cost vs. Accuracy Trade-off**	***Optimization Procedures***
Data Management, Storage & Visualization	**Smart Reanalysis**	**Design Space Search**
S/W Engineering Practices	**Approximations**	***Decomposition***
Human Interface	***Sensitivity Analysis***	

Product Data Model Example
(CAD Parametric Geometry Model)

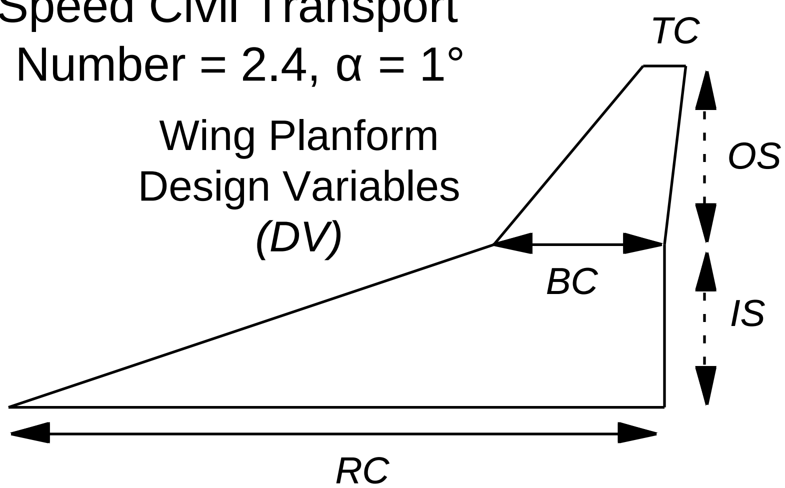


Sensitivity Analysis

- Computing derivatives of objective with respect to the design variables
- Methods
  - Finite differences
    - time consuming
    - difficult to pick Δ
  - Analytic
    - hard to code
    - changes with each application
    - fast
  - Automatic differentation
    - easy to use
    - accurate
    - can be time consuming

Automatic Differentiation of 3-Dimensional Navier-Stokes Flow Code (CFL3D)

High Speed Civil Transport
Mach Number = 2.4, α = 1°



Aerodynamic Coefficients	
C_L	Lift
C_D	Drag
C_Y	Side Force
CM_Y	Pitching Moment

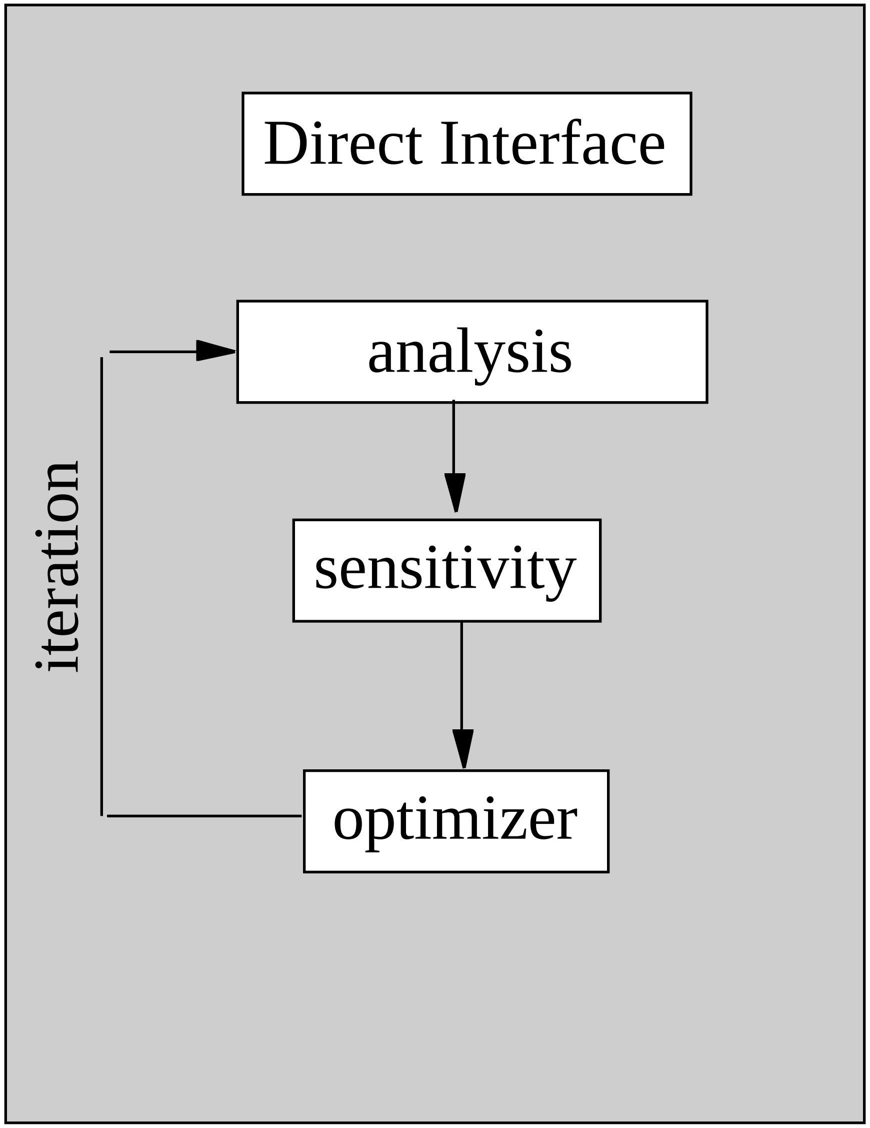
Sensitivity Derivatives - Derivatives of Aerodynamic Coefficients With Respect to Wing Planform Variables

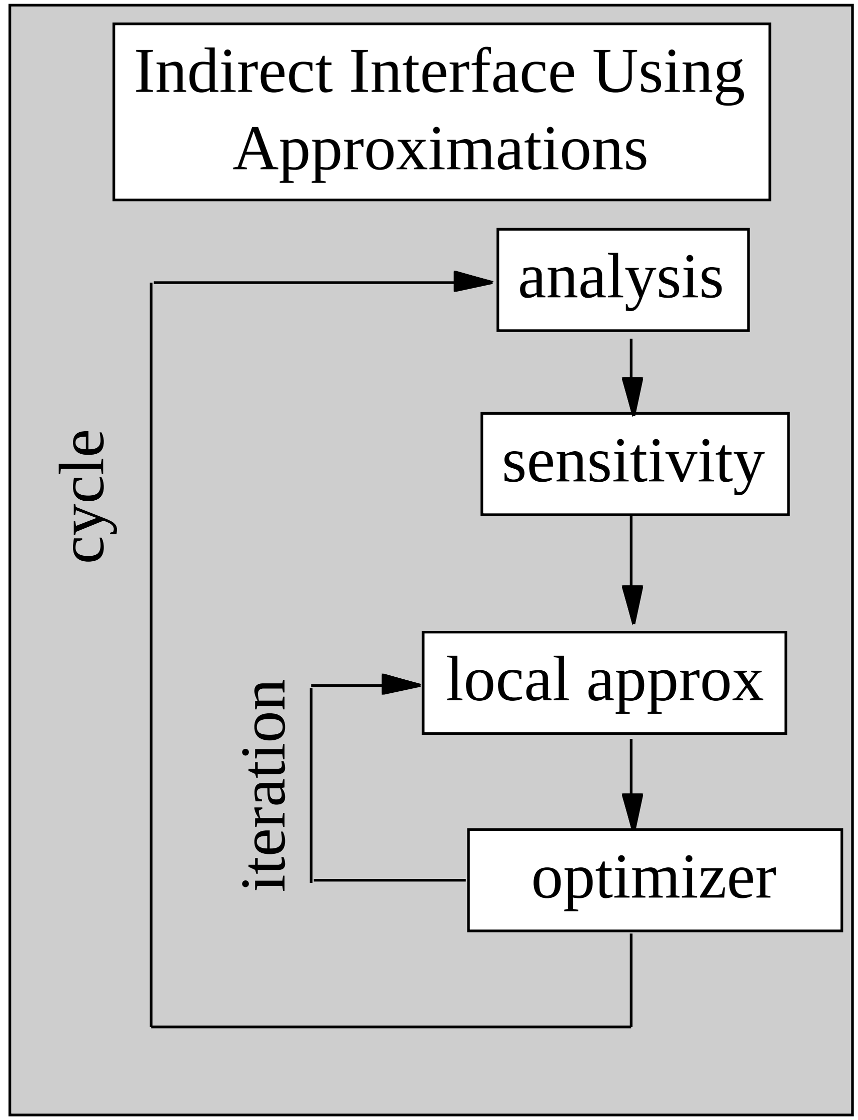
$$\frac{\partial CL}{\partial DV} \quad \frac{\partial CD}{\partial DV} \quad \frac{\partial Cy}{\partial DV} \quad \frac{\partial CMy}{\partial DV}$$

Time to Compute Sensitivity Derivatives (for 4 digits of Accuracy)

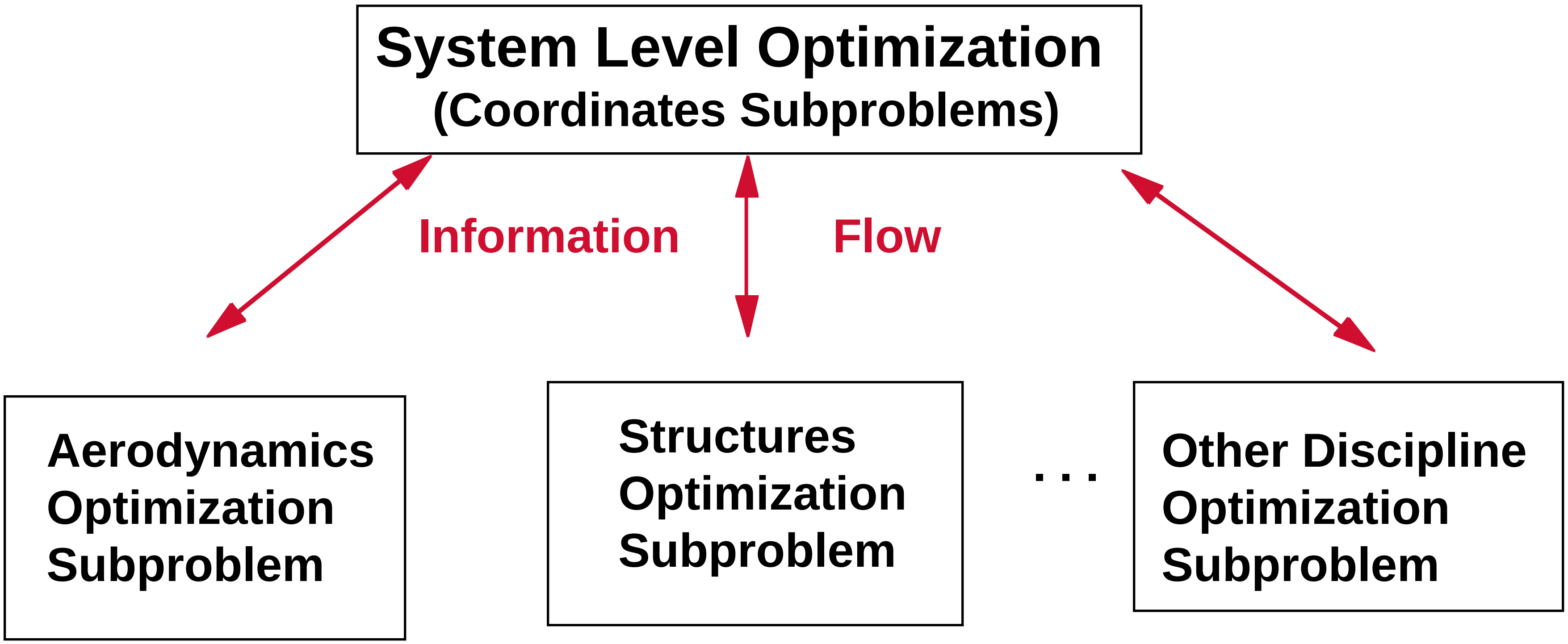
Automatic Differentiation (Residual reduced 4 orders) = 10.75 units
Finite Difference Method (Residual reduced 11 orders) = 15.00 units

Optimization Procedures





Decomposition



Preliminary Design

- Conventional Process
  - CAD-based geometry
    - surface
    - internal layout
  - Higher-order analysis
    - CFD
    - Finite Element
  - Discipline analysis & optimization
    - sequential or loosely coupled
    - discipline-based figure of merits (i.e., weight, thrust, drag, lift, etc.)
- Emerging MD Enhancements
  - Parametric CAD definition
  - Fully coupled multidiscipline analysis
  - Multidisciplinary optimization
    - Figures of merit
      - system performance and cost
      - multi-objective

Requirements for MDO Enhancements of Preliminary Design

- Information Science & Technology
  - heavy duty hardware; fast CPU(s), large memory & disk space
  - common parametric geometry model
  - software support
    - integration of proprietary, legacy, commercial, and research codes
      - code robustness, compatibility, & low algorithm noise
    - configuration control and data management
    - collaborative work environment; person-person/machine
- Design-Oriented MD Analysis
  - well posed interfaces for disciplines
    - automated grid generation (CFD, FEM)
  - discipline & MD sensitivities
- MD Optimization
  - MDO problem definition
    - design variables, objective(s), constraints
  - MDO strategy

Preliminary MDO Examples

- Aerospike Rocket Nozzle
  - Direct Optimization Approach
- High-Speed Civil Transport (HSCT)
  - Approximation Optimization Approach

MDO Applied to Aerospike Nozzle Design

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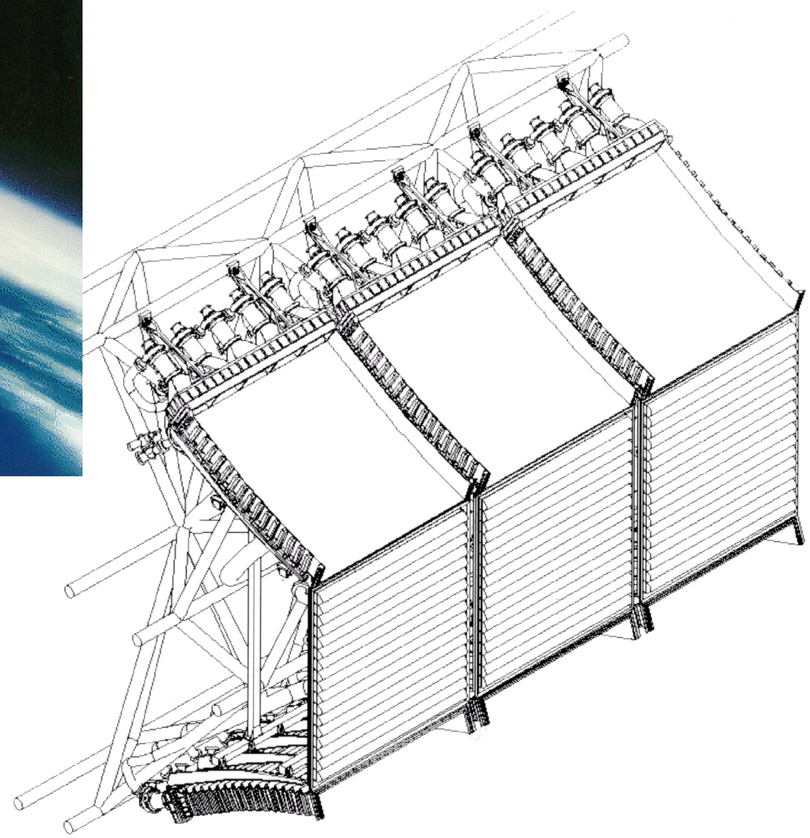
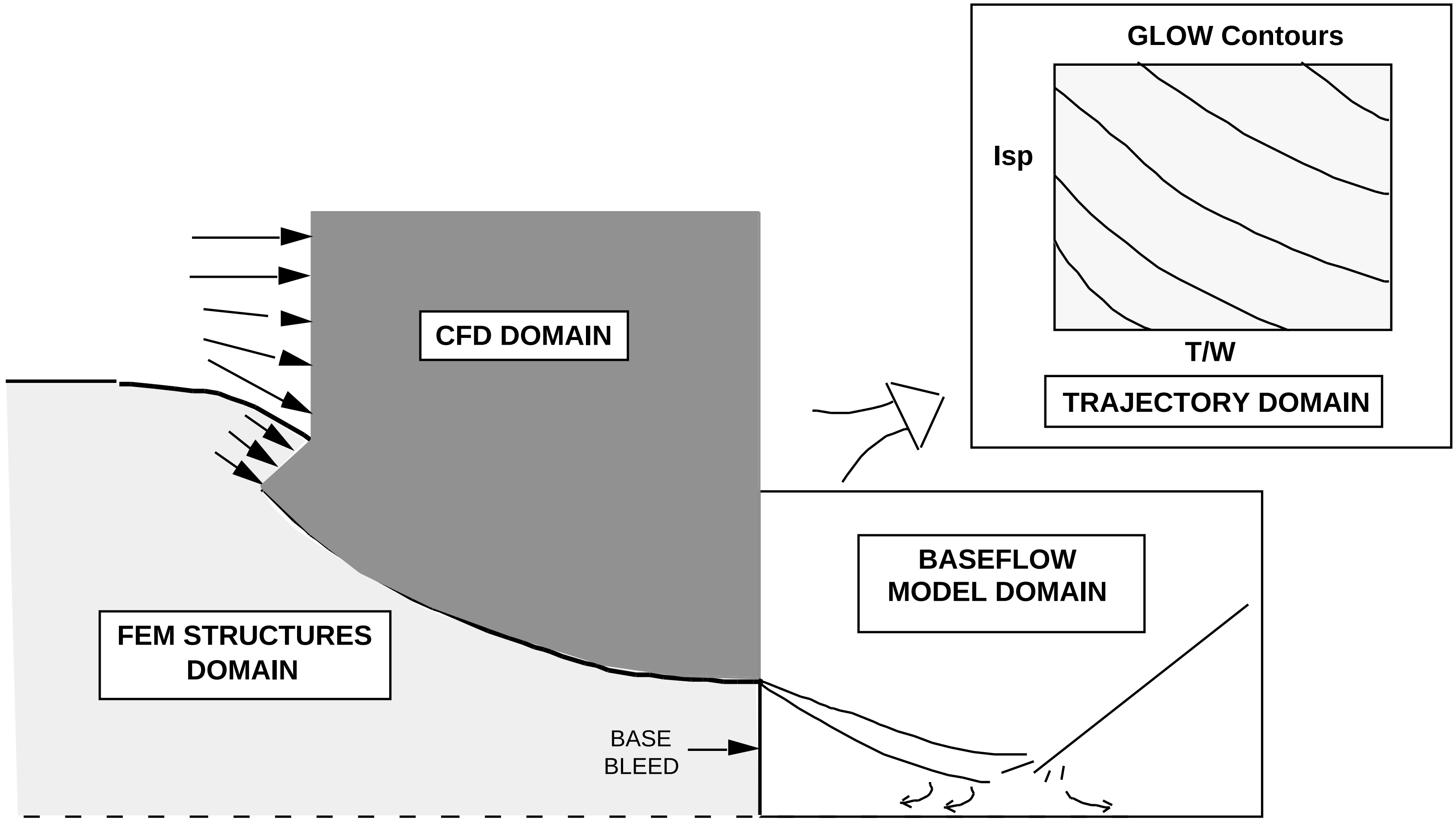


Aerospike Engine

Aerospike MDO Problem

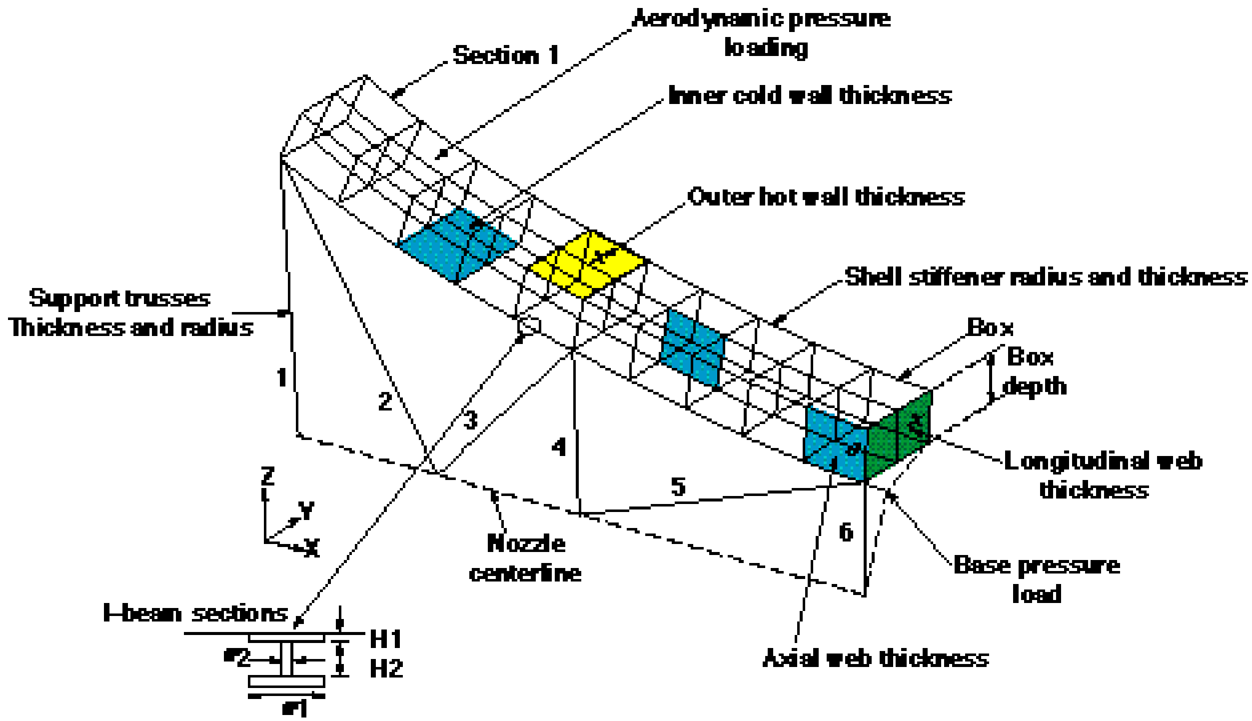
- Objective
  - minimize Vehicle Gross-Lift-Off Weight
- Design Parameters
  - 5 geometry variables
  - 13 structural variables
- Constraints
  - Stresses < allowable

Aerospike MDO Domain Decomposition

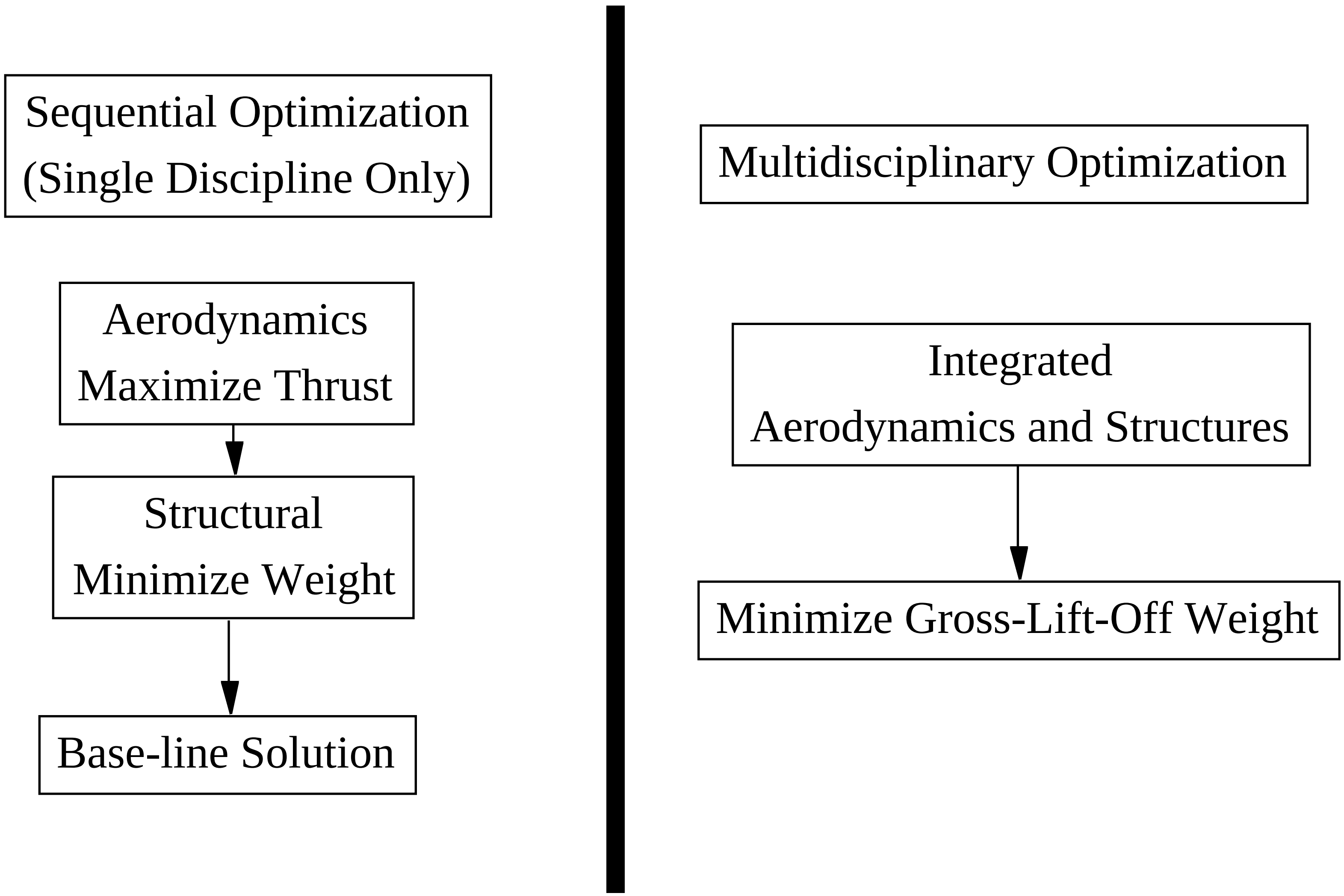


Nozzle Geometry Design Variables

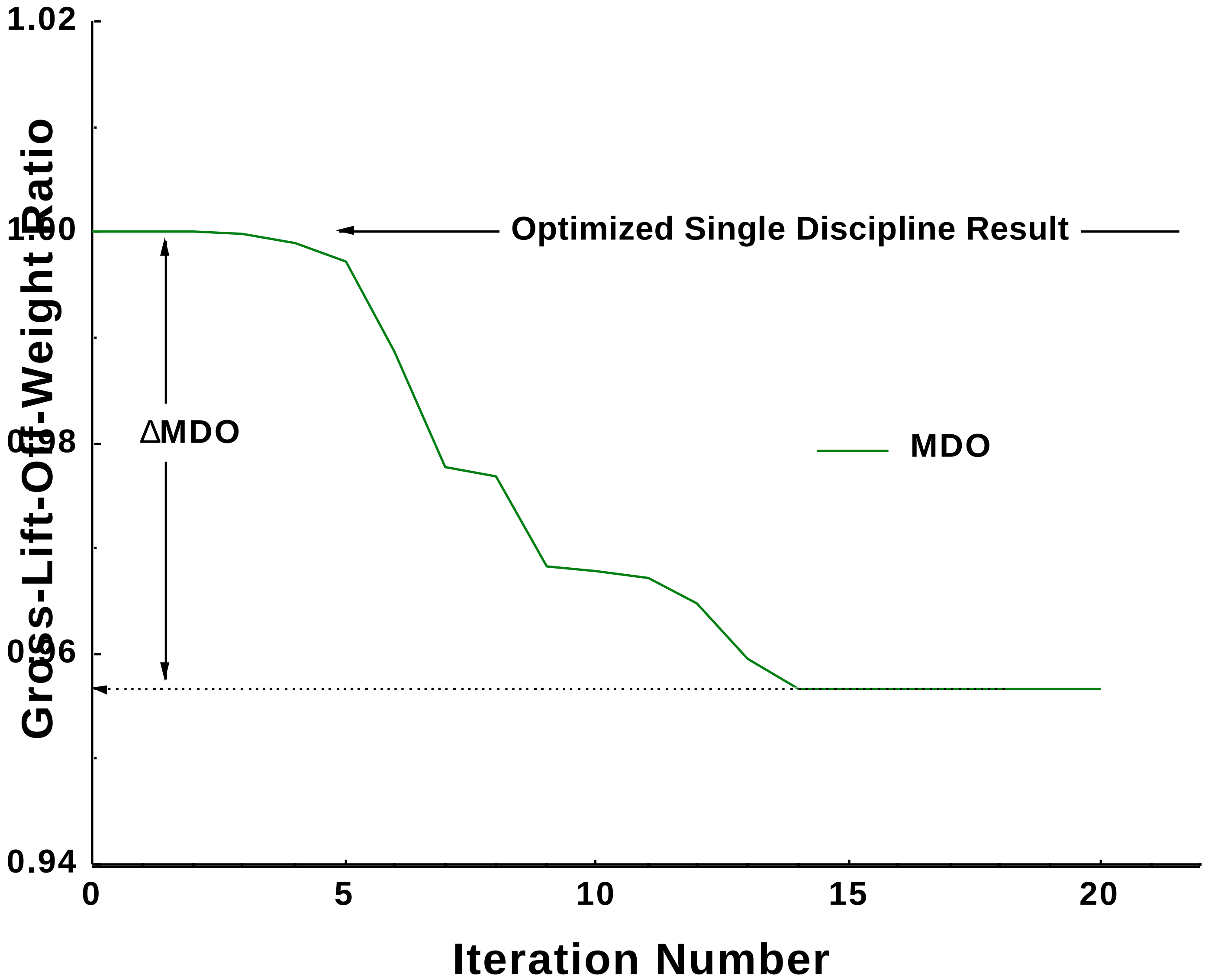
Aerospike Nozzle Structural Design Parameters



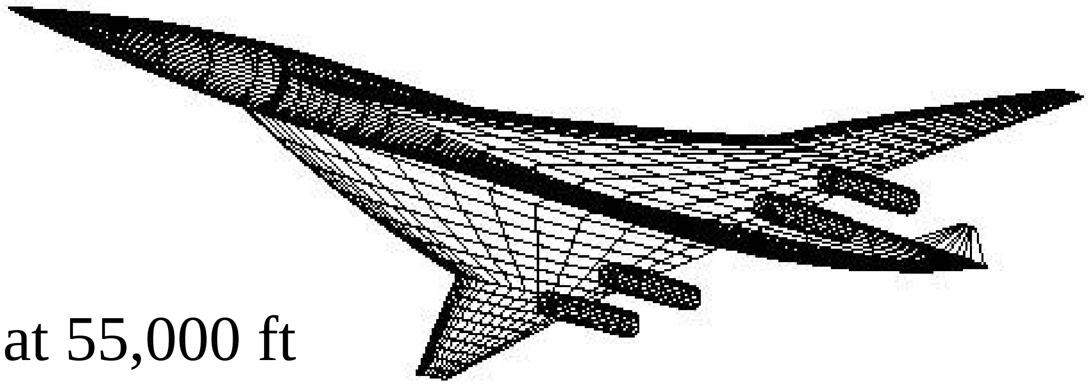
Aerospike Nozzle Optimization



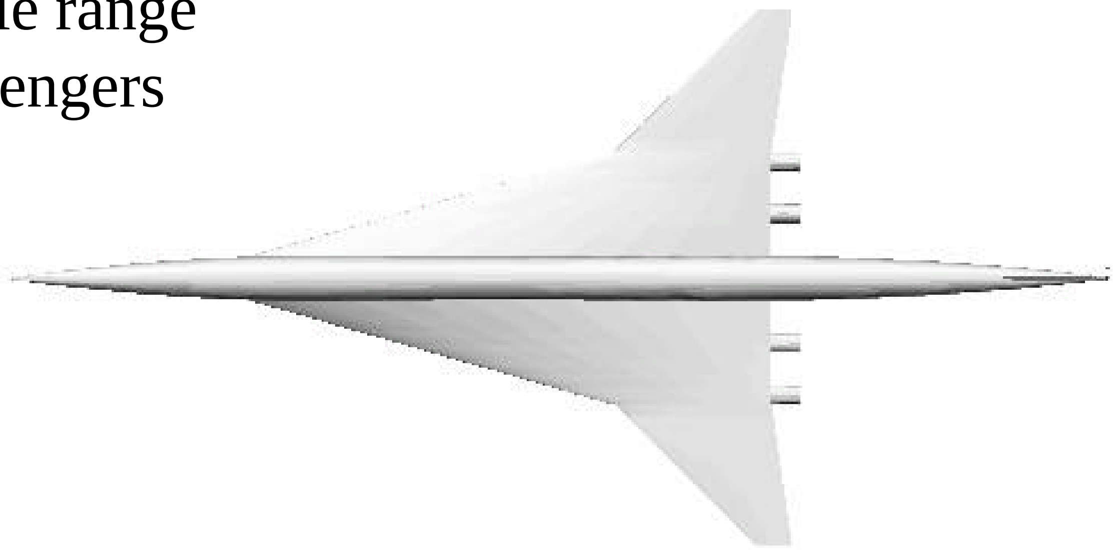
Aerospike Objective Function



MDO Applied to High-Speed Civil Transport (HSCT) Using FIDO



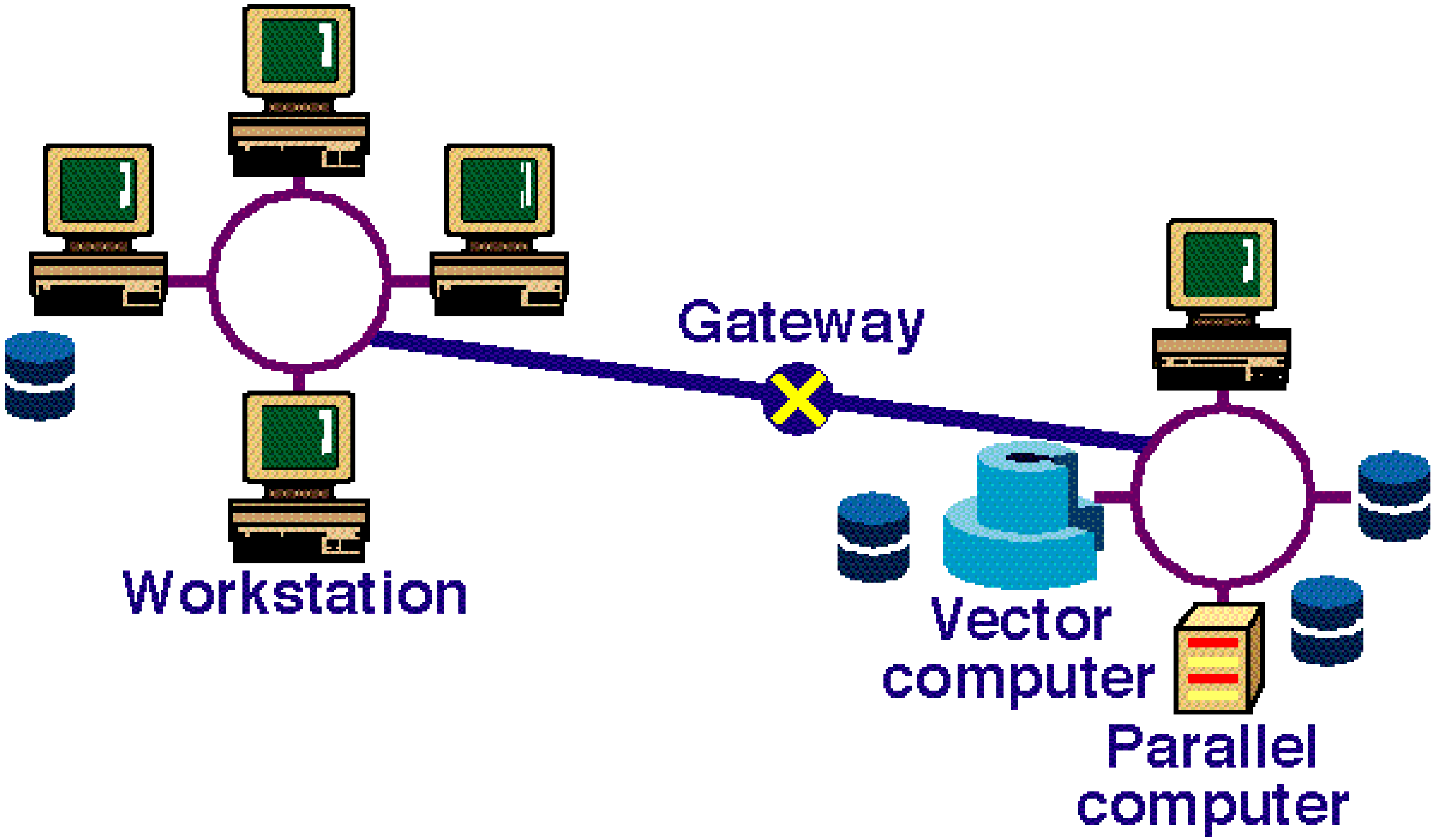
Mach 2.4 at 55,000 ft
6000-mile range
250 passengers



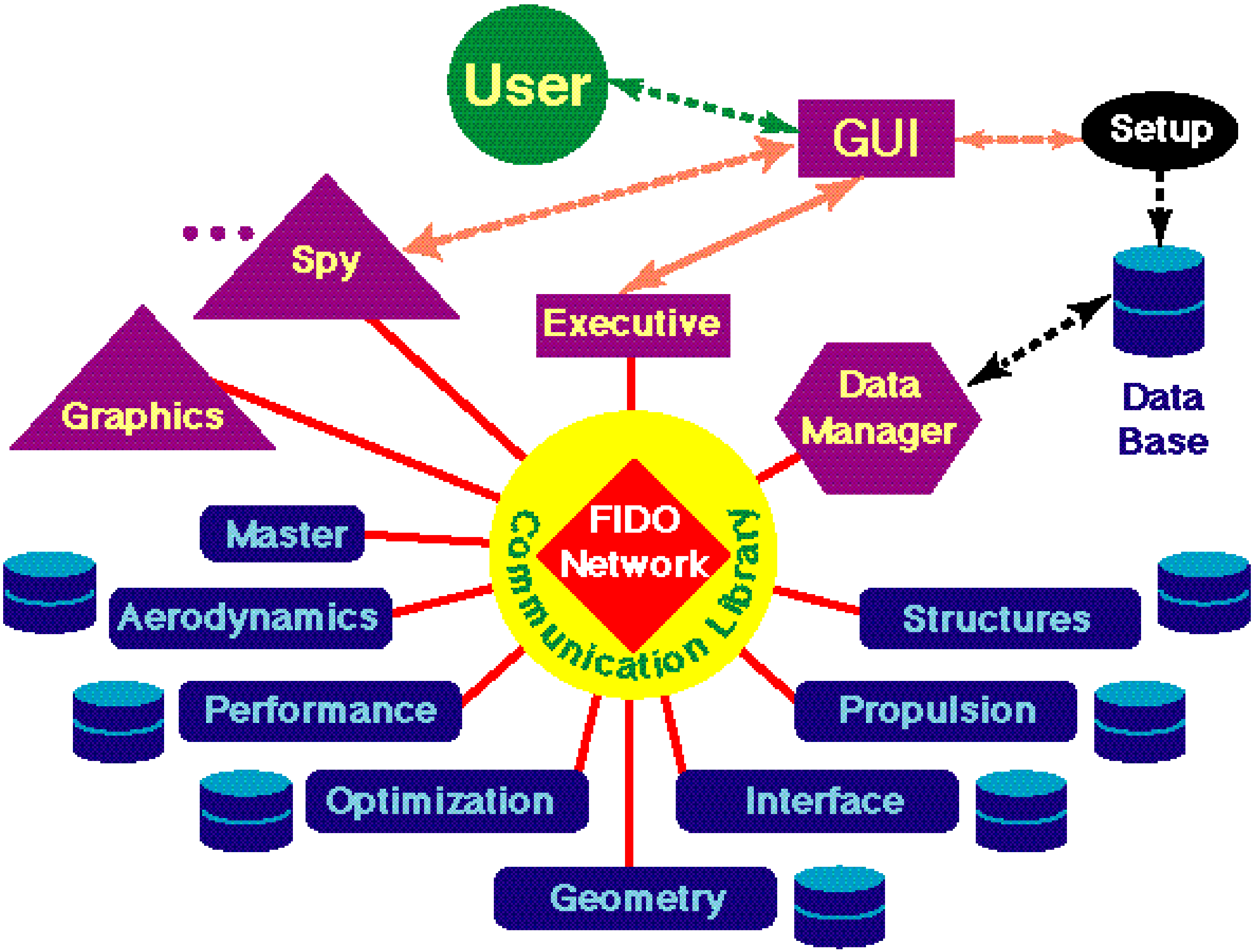
Framework for Interdisciplinary Design Optimization (FIDO)

Environment

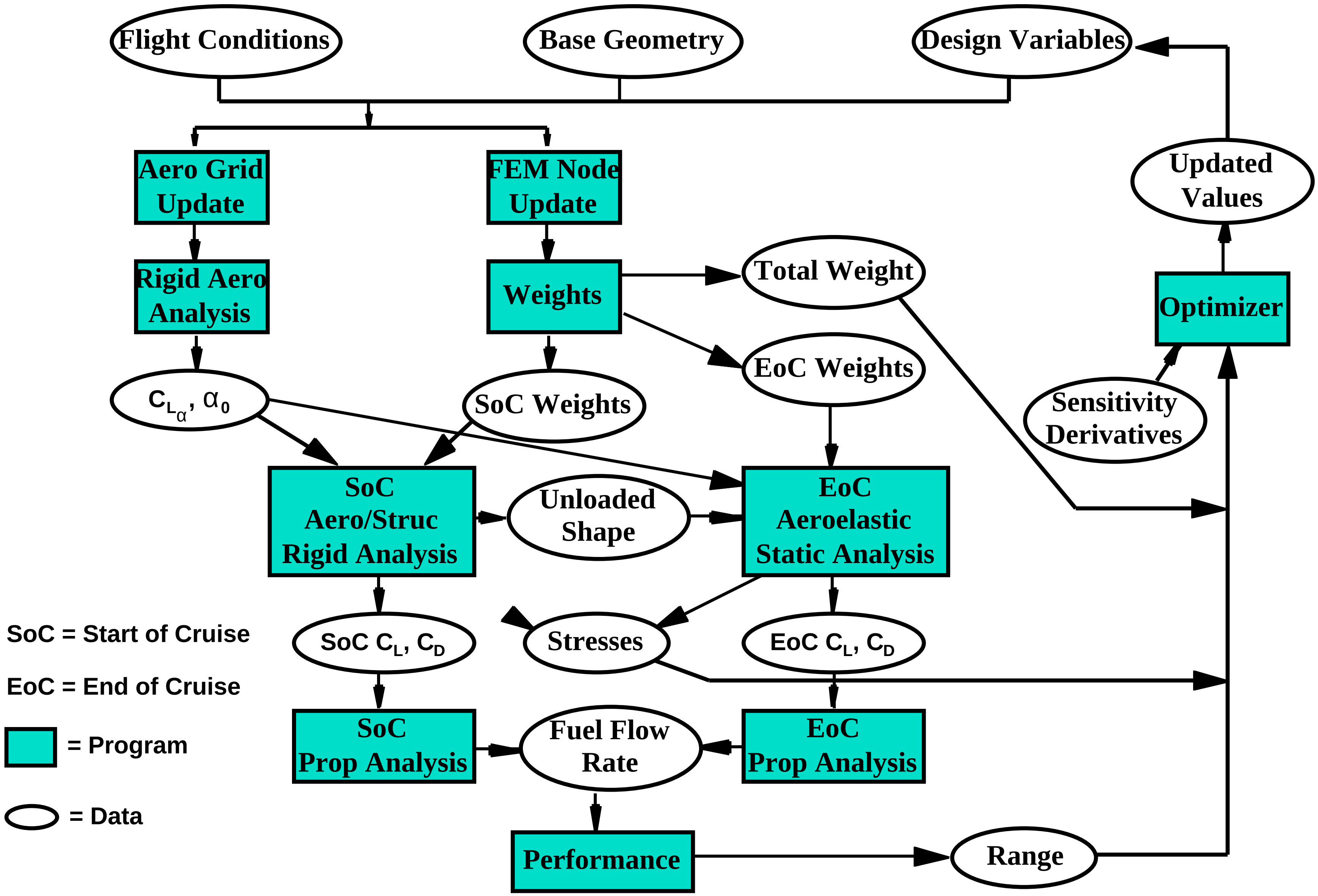
Heterogeneous Distributed Computing



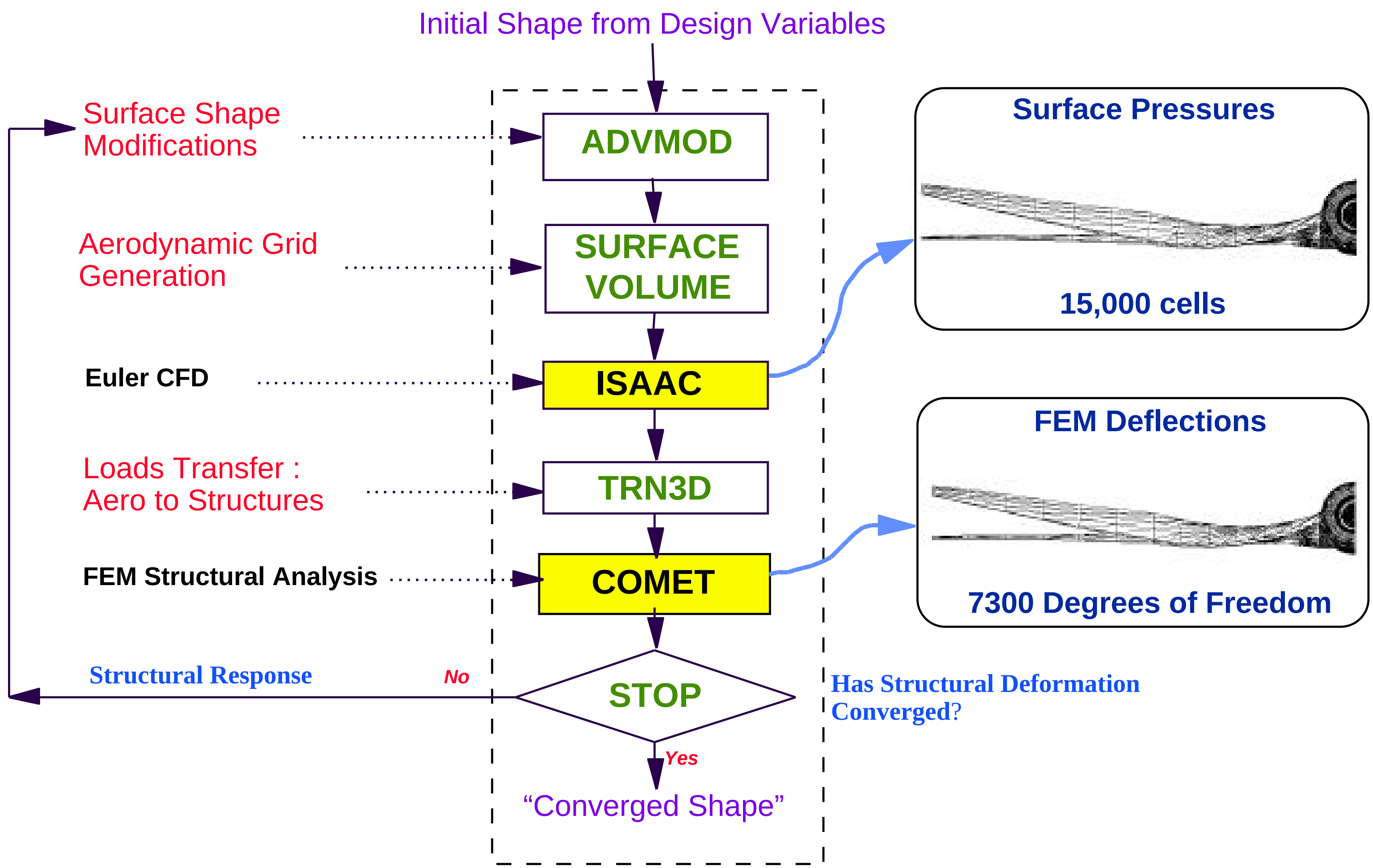
FIDO Execution System



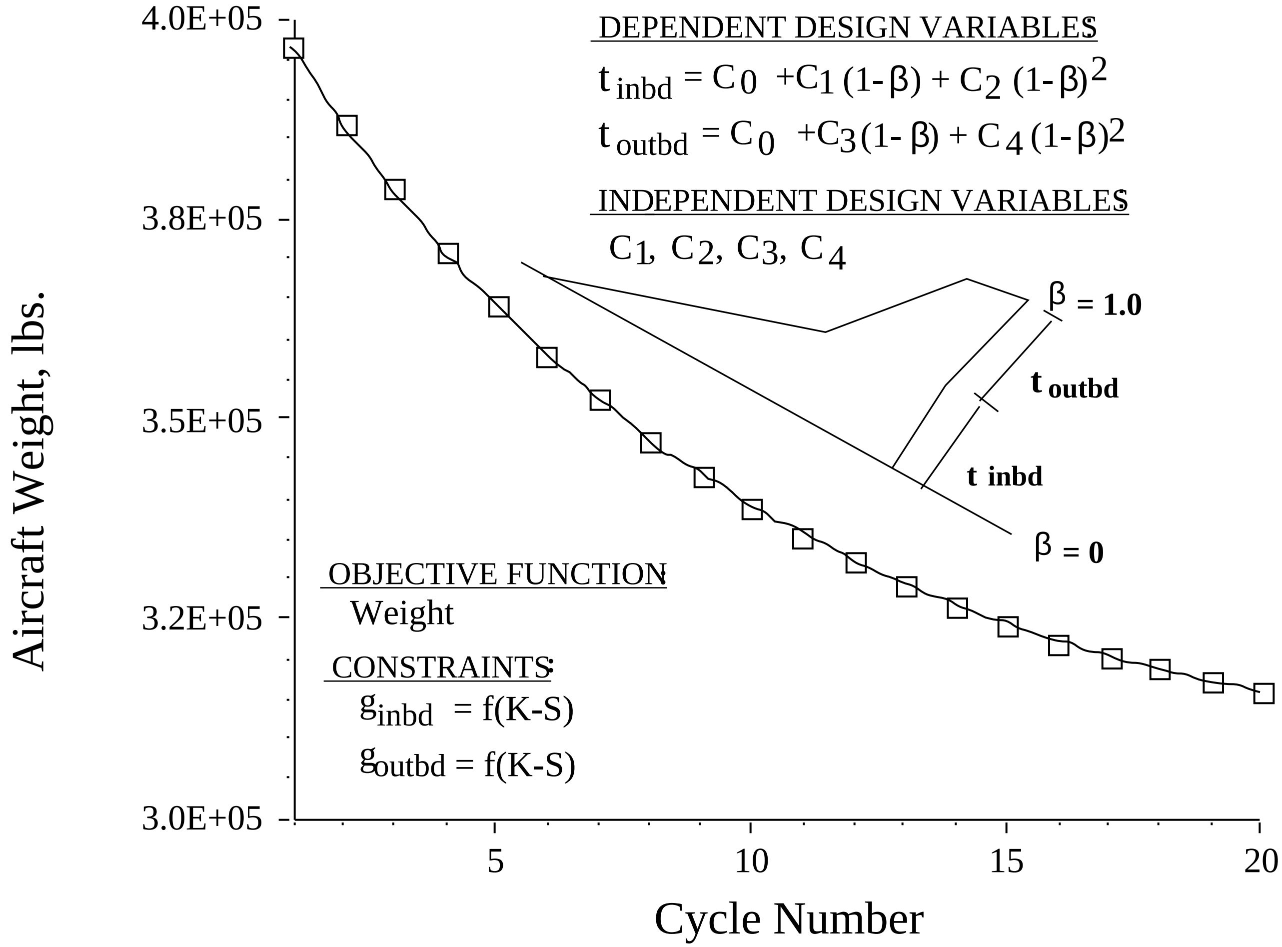
HSCT MDO Problem Diagram



Key Steps in FIDO Aeroelastic Loop



HSCT Design Optimization



Concluding Remarks

- MDO is much broader than just MD-Analysis; it contains elements from information sciences, design-oriented analysis and optimization methods
- The "$\Delta_{\mathbf{MDO}}$" is the improvement in design obtained from multidisciplinary synergy of the disciplines as demonstrated by the Aerospike nozzle application
- Application of MDO to preliminary design requires sophistication in the computational infrastructure and MDO algorithms
- Adoption of MDO in industry design process requires demonstrations which quantify
  - "$\Delta_{\mathbf{MDO}}$" improvement in design
  - reduction in time and effort in the design process